TECHNICAL NOTE:

PERFORMANCE OF TWO HOE-TYPE AIR DRILLS SOWING GREEN PEAS IN A CONSERVATION TILLAGE SYSTEM

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ABSTRACT. *A one year experiment was conducted in eastern Oregon to evaluate the performance of two different types of hoe-type air drills in terms of seeding depth uniformity, emergence, early plant growth, and crop yield when sowing green peas (*Pisum sativum *L.) in a tilled, leveled field. The seeding systems studied included a banded-row, flex frame air drill with seeding depth controlled by frame elevation and a single-row air drill with individual seeding unit depth control. Experimental design was a randomized complete block design with four replications. At the time of seeding, the field had approximately 5.6 t/ha of winter wheat (*Triticum aestivum *L.) residue on the soil surface. Depth of seed placement and date of emergence were recorded for 998 plants, while crop yield was determined by hand harvesting a 9.2-m^2 area. Despite the significant differences in drill configuration, few differences in performance were found. The banded-row, flex frame air drill without individual depth gauge wheels placed seeds as accurately as the single-row air drill equipped with individual seeding unit depth control. Standard deviation of the mean seeding depth, speed of emergence index, and the percentage of sown seeds that emerged were not significantly different between the two drills. Crop yield and crop yield components including plant population, pods per plant, peas per pod, and pea weight were also not significantly different. The results of this study suggest that in leveled field conditions, there is no benefit to drills equipped with individual seeding unit depth control in terms of seed depth uniformity, seedling emergence, stand establishment, or crop yield.*

Keywords. Sowing depth, Seedling emergence, Uniformity, No-till, Furrow opener, Depth control, Green pea, Conservation tillage, Drill performance, Air drill.

From 1990 to 2004, the number of acres planted to conservation tillage systems in the dryland growing regions of eastern Oregon and Washington increased by 52% from 340,000 to over 514,000 ha (Smiley et al., 2005). A consequence of this transition to conservation tillage has been an increased interest in the performance of conservation tillage drills and their ability to establish plant stands in heavy crop residues (Raoufat and Mahmoodieh, 2004; Doan et al., 2005a). Rapid, uniform stand establishment is essential for maximizing yield for most crops, but especially in edible green peas (*Pisum sativum* L.) where uniform maturation is critical not only for crop yield but also crop quality (Pumphrey et al., 1979; Kraft and Wilkins, 1989).

Numerous studies have been conducted showing the significant effect opener type has on seeding depth uniformity, emergence rate, stand establishment, early plant growth, and crop yield. Many of these studies compared the performance of hoe-type to disc-type openers (Allen, 1988; Doan et al., 2005a, 2005b) or concentrated on the performance of experimental openers (Tessier et al., 1991a, 1991b; Wilkins et al., 1992). Limited studies have been conducted using modern, commercial equipment, especially in green peas.

Major differences between models of modern commercial hoe-type, conservation tillage air drills include seed dispersal method, namely paired row (banded) versus single-row seeding, and whether seed depth is controlled by main frame elevation or by depth control components on individual seeding units. Desbiolles (2003) studied the effect of seed bed utilization (SBU), the proportion of row spacing that is effectively occupied by the crop row on crop yield for a wide range of modern openers. In the four-year, two-location study, Desbiolles found that opener systems that achieved 65% to 70% SBU had significantly higher grain yield as compared to the average performance of systems with lower SBU's. In a drier season, SBU was strongly correlated with wheat (*Triticum aestivum* L.) and lentil (*Lens culinaris* L.) yields with R^2 values of 0.80 and 0.95, respectively. Heege (1993) also reported that sowing systems such as broadcast seeding and precision drilling which more uniformly distribute seeds over the entire field area as compared to conventional drilling increased yield of small grains, rape

(*Brassica napus L.*), and field beans (*Phaseolus vulgaris*) by 5% to 11%. In the same study, Heege also found that seeding units equipped with gauge wheels for individual seeding unit depth control had better seeding depth uniformity as measured by the standard deviation of the mean seeding depth and emergence as compared to seeding units that were not outfitted with gauge wheels. When sowing small grains, seeding units equipped with and without gauge wheels had standard deviations of the mean seeding depth ranging from 4 to 9 mm and 6 to 11 mm, respectively, while emergence rates were 82% and 76%, respectively.

Others have also studied the merits of drills with individual seeding unit depth control. Morrison and Gerik (1985) evaluated the effect of various gauge wheel positions on seed depth uniformity, emergence, and plant growth vigor when seeding corn (*Zea mays* L.) and sorghum (*Sorghum* Moench) with an experimental disc-type drill. Variations in seeding depth ranged from 6.7 to 11.3 mm and significantly affected corn and sorghum emergence and corn plant weight. They concluded that accurate planting depth control is needed to minimize depth related plant vigor and growth variability. Chen et al. (2003) found that when depth gauge wheels were used on individual seeding units in corn, wheat, and soybean (*Glycine max* L. Merr.), emergence rate and final plant populations were significantly higher by more than 39% and 32%, respectively, in three of the five trials conducted. Crop yields, however, were not significantly affected.

This body of literature indicates that method of seed distribution and accuracy of seed placement can have significant effects on stand establishment and crop yield for most crops. Additional studies on the effects of these parameters are needed to optimize crop production. The objective of this study was to compare the performance of two different types of conservation drills, namely a banded-row, flex frame air drill with seeding depth controlled by frame elevation and a single-row air drill with individual seeding unit depth control, in terms of seeding depth uniformity, emergence, early plant growth, and crop yield in green peas.

METHODS

AIR DRILL DESCRIPTIONS

The two hoe-type conservation tillage drills (*ASAE Standards*, 2001b) evaluated in the study included a Horsch Anderson (Horsch Anderson, Andover, S.D.) banded-row, flex frame air drill and a Conserva Pak (Conserva Pak Seeding Systems, Indian Head, Saskatchewan, Canada) single-row air drill with individual seed row depth control (fig. 1). The commercial scale, 9.1-m wide, Horsch Anderson air drill was equipped with AE-10 Anderson openers spaced 22.8 cm apart. The AE-10 Anderson opener was a relatively high disturbance, double shoot opener that placed liquid fertilizer 6.4 cm below a 12-cm wide band of seeds. The flex frame air drill was comprised of three ranks and three frame sections. Seeding depth was controlled by frame section elevation using a gang of pneumatic tires that also served as press wheels. The Conserva Pak air drill was a three rank, 3.7-m wide plot drill with 12 openers spaced 30 cm apart. Rank spacing, row spacing, and seeding units were identical to those used on commercial sized units. Each Conserva Pak

seeding unit was configured with two hoe openers, one for delivering fertilizer and the other for delivering seed. The fertilizer opener had a 1-cm wide point that was positioned approximately 30 cm ahead of, and 2.5 cm to the side of, the following seed opener. Vertical separation between seed and fertilizer for the Conserva Pak air drill was set to the same 6.4-cm distance as the Horsch-Anderson air drill. Seeding depth for individual seeding units was controlled by hard plastic gauge wheels that also functioned as press wheels. Travel speeds for the Horsch-Anderson and Conserva Pak air drills were 9.7 and 6.4 km/h, respectively, as per manufacturer recommendations. Because the respective manufacturer's brand names are not descriptive of the major functional differences between the two drills, henceforth the Horsch Anderson and Conserva Pak drills will be referred to as the "banded-row - no gauge wheel" (BR-NGW) drill and the "single-row - gauge wheel" (SR-GW) drill, respectively.

TEST SITE DESCRIPTION

The study was conducted on a commercial field near Milton-Freewater, Oregon, where the soil was an Athena silt loam (fine-silty, mixed, mesic Pachic Haploxerolls) and annual precipitation near the site was 500 mm. The previous crop was winter wheat which yielded approximately 4.7 t/ha in 2003. Conservation tillage practices that are typical for the
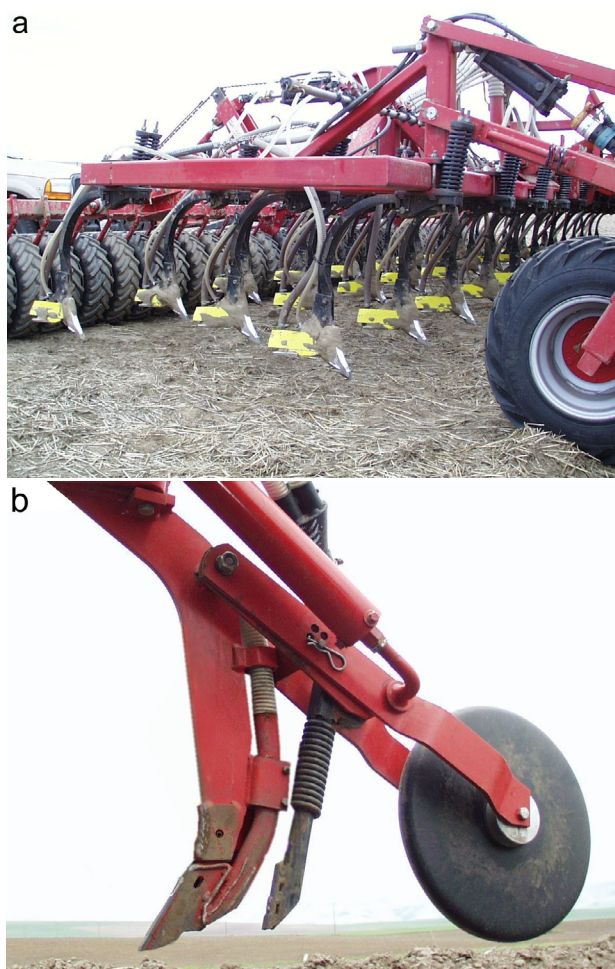

Figure 1. Drill units used in green pea seeding trials included (a) Horsch Anderson flex frame, banded-row air drill with seeding depth controlled by frame elevation and (b) Conserva Pak hoe-type row air drill with individual depth control.

region were used to prepare the field prior to sowing. The test site was lightly disked in the fall of 2003 and harrowed twice the following spring to level the field and incorporate an application of the herbicide imazethapyr. Field leveling is a necessary practice to facilitate mechanical harvest of low hanging pods. It should be noted that drill performance in terms of seeding depth uniformity would be different and presumably more variable for both drills if the field had not been tilled prior to sowing. A broadcast-spray application of glyphosate herbicide was made just prior to seeding to control weeds and volunteer wheat. Approximately 5.6 t/ha of flattened, unanchored wheat residue remained on the soil surface at the time of seeding, and therefore meets the definition of a conservation tillage system (*ASAE Standards*, 2001b).

A randomized complete block experimental design with four replications was used with the previously described BR-NGW and the SR-GW seeding systems as treatments. Test plots measured 45.7 m in length, but had differing widths that matched the drill widths of the BR-NGW and the SR-GW drills of 9.1 and 3.7 m, respectively. Each drill was calibrated to apply 235 kg/ha of green pea variety 'Solution' seed, 22 kg/ha of N, 11 kg/ha of P_2O_5, and 12 kg/ha of S. Although the BR-NGW drill applied fertilizer in liquid form and the SR-GW drill applied granular fertilizer, fertilizer formulation was not expected to affect drill performance in terms of the performance parameters measured, including seed placement accuracy and seedling emergence rate. Fertilizer formulation was expected to have minimal effect on seedling emergence rate since the drills applied identical quantities of fertilizer, the application rate was low and both drills were adjusted to place fertilizer a sufficient distance of 6.4 cm below the seed. The plots were sown 10 March 2004 with both drills adjusted to place seeds at a target depth of 5 cm. After seeding, the field was leveled using a tine toothed harrow and packed. These operations affected the seeding depths of the both drills, but especially the SR-GW drill where the effective seeding depth was increased by about 2 cm since the leveling and packing operations filled the furrow left by the drill's narrow press wheel with soil. A consequence of this was that seed depth placement accuracy at the time of seeding could therefore not be recorded. Despite this limitation, the seeding depth performance results of this study are useful since they represent those that would be obtained in a commercial farming operation where post seeding leveling and packing is commonly practiced to facilitate harvest of low hanging pods.

MEASUREMENTS

Gravimetric soil water content (*ASAE Standards*, 2001a) was measured the day of seeding by collecting a total of four samples randomly located near the corners of, but outside the rectangular plot area. Soil cores were sectioned at depth intervals of 15 cm for the first 30 cm and then every 30 cm to the maximum depth of 120 cm. Samples at each depth interval were combined to form a composite sample. The 0- to 15-cm sample depth interval was taken to be representative of the seed zone soil water content. Seed zone soil temperature in the seed row was measured hourly in each plot at a depth of 7.6 cm, slightly below the target seeding depth of 5 cm, using an Onset StowAway Temp logger (Onset Computer Corporation, Bourne, Mass.).

Plant counts were taken daily for the first 30 days after planting and then on the 36th and 40th day after planting from sample areas randomly located in each plot. Sample areas measured 1 m long by 1.8 m wide equivalent to 8 and 6 rows for the BR-NGW and SR-GW drills, respectively. Since sample area widths were narrower than the widths of the drills, sample areas were randomly located across the width of each plot to ensure the data were collected from the entire drill width and therefore representative. Plant counts taken the 40th day after planting were recorded individually for each row and used to determine the final plant population for each row and for each sample area. Percent emergence for each observation day was calculated as observed plant population per unit area (plants/m²) divided by the product of seeding rate (seeds/ m²) multiplied by the fraction of viable seeds. Percent emergence was plotted versus accumulated heats units (AHU) using 4.4°C as a base temperature (Wilkins et al., 1992). Seedling emergence rate (plants m^{-2} degree-day^{-1}) resulting from the use of each drill was determined from the slopes of a regression lines fit to the data from 5% emergence to 70% emergence. Air temperature and other climatic information including precipitation, wind speed and relative humidity were recorded using a custom-designed weather station installed near the field border (Oviatt and Wilkins, 2002). A speed of emergence index (SEI) formula was developed to provide a second method for comparing emergence rate differences as:

$$SEI = \sum_{i}^{n} \frac{N_i}{A \times AHU_i} \qquad (1)$$

where

SEI = speed of emergence index (plants m^{-2} degree-day^{-1})

N_i = number of newly emerged plants on the ith day after planting

A = area of plant count area (m²)

AHU_i = accumulated heat units (4.4°C base) on the ith day after planting (degree-day^{-1} in °C)

n = number of days after planting used to determine final plant population (40 days).

This equation is similar to the SEI developed by Maguire (1962) except that here, AHU is used in place of calendar days.

Seeding depth was determined on the 42nd day after planting for the plants in the sample areas where the plant count observations were made using the method described by Wilkins et al. (1992). Briefly, the seedling portions that remained in soil were excavated, passed over a set of screens to separate plant material from soil, and the distance from the center of the seed to the cut surface was measured for each seedling and recorded separately for each row. Above ground plant material was also collected, dried, and weighed to determine above ground seedling dry matter. Seeding depth uniformity was taken to be characterized by the standard deviation of the mean (Chen et al., 2003).

To determine crop yield, plants from randomly located sample areas measuring 3.4 m long × 2.7 m wide (12 and 9 rows for the BR-NGW and SR-GW drills, respectively) in each plot were pulled by hand, bulked, and then threshed using a small sample de-viner. The threshed peas were separated using a sample grader/cleaner, weighed and tenderometer reading determined. Yield was adjusted to an

equal 100 tenderometer reading (Pumphrey et al., 1975). Twenty-five plants near each harvest sample area were cut off at ground level and used determine average plant height, number of pods per plant, peas per pod, pea weight and pea weight per plant.

A t-test was performed using SAS (SAS Institute Inc., Cary, N.C.) to determine statistical differences (P = 0.10) between treatment means while the F-test was used to determine statistical differences between standard deviations of treatment means (Schulman, 1992). Correlations between final emergence and seeding depth and between final emergence and standard deviation of seeding depth were determined from r-squared values of quadratic and linear regression equations fit through the data (Morrison and Gerik, 1985; Heege, 1993)

RESULTS

SOIL CONDITIONS

Gravimetric soil water content at the time of seeding was 21% dry-basis in the seed zone (0- to 15-cm soil depth) and more than 19% at depths below 15 cm. Two weather systems passed through the region 15 days after planting and 34 days after planting and provided 6.9 and 11.0 mm of precipitation, respectively. These rainfall events ensured adequate moisture for pea seed germination and vigorous early plant growth. Soil temperature measured at a depth of 7.6 cm was taken to be representative of the seed zone temperature and averaged 9.8°C on the day of seeding. For the first 40 days after planting, average soil temperature in the BR-NGW and SR-GW treatments were 11.9°C and 11.7°C, respectively. Average daily soil temperature differences between the two treatments were less than 0.5°C throughout the experiment, not statistically significant (P = 0.10) and therefore not expected to cause differences in seedling emergence rates between treatments.

SEED PLACEMENT

Seeding depth measurements were recorded for 998 seedlings with the results summarized in table 1. Mean seeding depth for the BR-NWG drill was 6.0 cm and significantly shallower than the SR-GW drill where the mean seeding depth was 8.1 cm. Frequency distributions of seeding depth for the two drills are shown in figure 2a. Both distributions appear to be normally distributed about their respective means, with the peak shifted slightly to the left for BR-NGW drill and slightly to the right for the SR-GW drill. This observation is confirmed by the results shown in table 1 where the median seeding depths of the BR-NWG and SR-GW drills are 0.1 cm lower and 0.1 cm higher than their respective mean seeding depths. This difference can be seen more clearly in figure 2b where the recorded seeding depths of the SR-GW have been reduced by 2.1 cm so that the mean seeding depth of both drills has the same value of 6.0 cm. The distribution patterns are essentially mirror images of each other about the mean seeding depth, with BR-NGW drill placing a slightly higher percentage of seeds shallower than the mean seeding depth and the SR-GW drill placing more seeds deeper than the mean depth. Despite this difference, the seeding depth frequency distributions of the two drills were nearly identical when adjusted for differences in mean seeding depth. The percentages of seeds within a given depth

Table 1. Green pea seeding depth results when sown with two types of hoe-type air drills in 2004.

Drill[a]	Mean (cm)	SE[b] (cm)	Median (cm)	SD[c]
BR-NGW	6.0 a[d]	0.06	5.9	1.51 a[e]
SR-GW	8.1 b	0.08	8.2	1.54 a

[a] BR-NGW is the banded-row air drill without individual gauge wheel depth control.
SR-GW is the single-row air drill with individual gauge wheel depth control.
[b] SE is standard error of the mean seeding depth.
[c] SD is standard deviation of the mean seeding depth.
[d] Means followed by the same letter in the column are not significantly different by t-test test (P = 0.10).
[e] Means followed by the same letter in the column are not significantly different by F-test test (P = 0.10).

interval for the two drills were within one standard error of the mean of each other for 10 of the 14 seeding depth intervals examined (fig 2). In the four intervals where the difference in percentage was greater than one standard error of the mean, the maximum difference was only 6.5%.
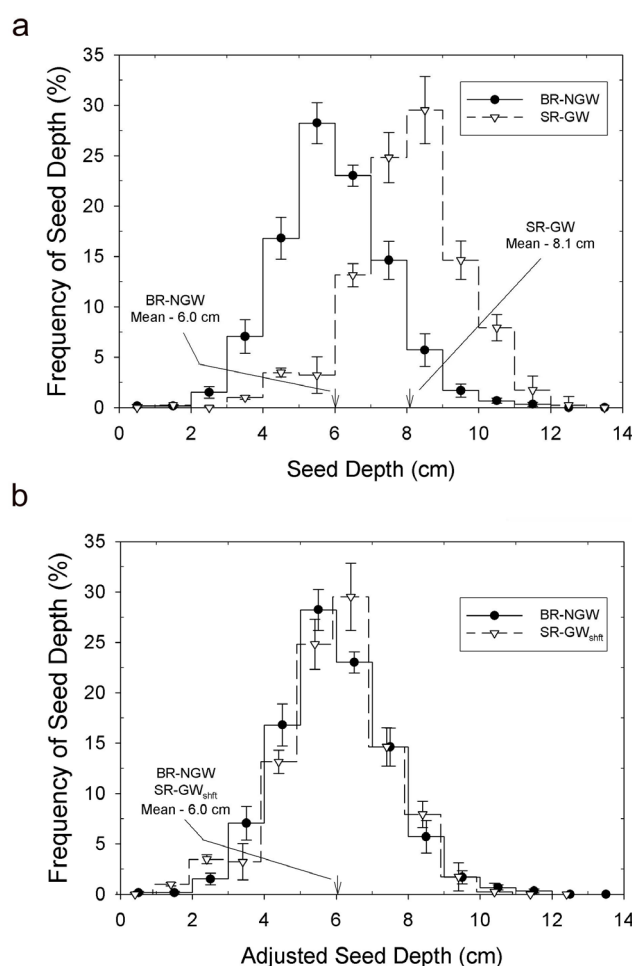

Figure 2. Seed depth frequency distributions for green peas sown with two types of hoe-type air drills in 2004 -- the banded-row air drill without individual gauge wheel depth control (BR-NGW) and the single-row air drill with individual gauge wheel depth control (SR-GW). (a) Original data, (b) SR-GW data shifted so that the mean seeding depth of the SR-GW has the same value of 6.0 cm as the BR-NGW drill. Error bars indicate one standard error of the mean (n = 4).

Seeding depth uniformity as measured by the standard deviations of the mean seeding depth was also nearly identical for the two drills. The standard deviation of the mean seeding depth for the BR-NGW and SR-GW drills were 1.51 and 1.54 cm, respectively, and not statistically different from each other (table 1). The standard deviation of the BR-NGW drill found in this study is in agreement with the findings of the AFMRC (1995) who evaluated the same type of opener and reported a similar standard deviation in seeding depth of 1.5 cm. Although the SR-GW drill equipped with individual seeding unit depth control was expected to have less variation in seed depth uniformity as compared to the BR-NGW drill without individual seeding unit depth control, the standard deviation of 1.54 cm of the SR-GW drill is in agreement with those of Doan et al. (2005b) who tested the same opener in peas (*Pisum sativum* L.) and found that standard deviation of seeding depth ranged from 0.56 to 0.69 cm during one crop year and from 1.46 to 1.80 cm the following crop year. No explanation was given for this drastic difference in seed depth uniformity between crop years, however soil moisture at the time of seeding was much drier in the year where seeding depth was more variable. Finding no differences in seeding depth uniformity between drills with and without individual seeding unit depth control is not an unprecedented result. Choudhary et al. (1985) measured the seeding depth uniformity of various drills and also found no difference in standard deviation of seeding depth between a banded-row drill with depth controlled by frame elevation and a hoe-type opener with individual seeding unit depth control when seeding peas in a silt loam soil. Considering these results in conjunction with those of this study, there is indication that in certain field conditions, drills with individual seeding unit depth control have no advantage in seeding depth uniformity over drills without individual depth control.

Another way of interpreting the performance of the two drills is to examine the probability of an individual seed being placed within a given distance of the mean seeding depth by assuming the seeding depth data are normally distributed about the mean. Since the standard deviations of the mean seeding depths were similar for the two drills, their performance by this measure was also very similar. The probability of a seed being placed within 1 cm of the mean for the BR-NGW and SR-GW drills were 49.2% and 48.4%, respectively, and 81.5% and 80.6%, respectively, for being within 2 cm of the mean. The probability of a seed being placed more than 2.5 cm away from the mean were 9.8% and 10.2% for the BR-NGW and SR-GW drills, respectively.

EMERGENCE

Because the seeding depth was greater for the SR-GW drill as compared to the BR-NGW drill, first emergence was delayed by 2.5 days as shown in table 2. The delayed emergence of the SR-GW drill can be seen more clearly in figure 3 where emergence is plotted versus AHU for the two drills. Although the drills had virtually identical seeding depth uniformity, the rate of emergence as determined from the slope of a regression line from 5% emergence to 70% emergence for the SR-GW drill was significantly greater than the BR-NGW drill with values of 1.4 and 1.1 plants m^{-2} dd^{-1}, respectively (fig. 3, table 2). A possible explanation for this was the significant difference in seeding depth between the two drills. The deeper seeded SR-GW seedlings were more mature prior to emergence and therefore grew a greater distance per AHU as compared to the BR-NGW drill and consequently emerged at a faster rate. The other estimate used for comparing rate of emergence, the speed of emergence index (SEI), however showed no differences between the two drills. The SEI for the BR-NGW was 0.8 plants m^{-2} dd^{-1} and not significantly different from the 0.7 plants m^{-2} dd^{-1} SEI of the SR-NGW drill.

Despite the difference in mean seeding depth, final plant population, percent of seeds planted that emerged and seedling weight 40 days after planting were not significantly different between the two drills (table 2). Both drills had final plant populations of over 97 plants m^{-2} with more than 82% of the sown seeds emerging. These results were not expected
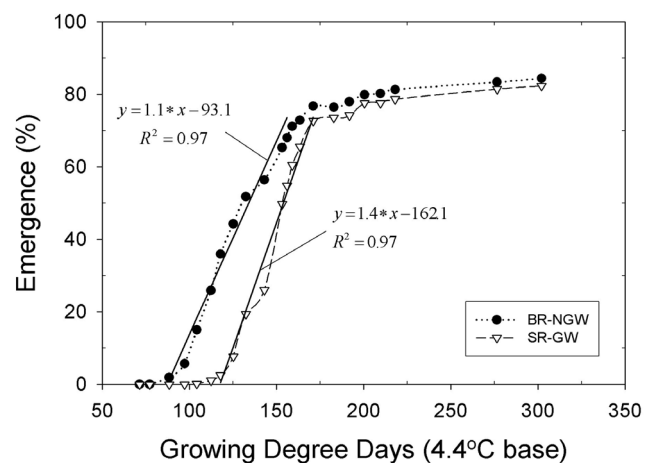

Figure 3. Green pea seedling emergence (%) as a function of accumulated heat units for two types of hoe-type air drills – the banded-row air drill without individual gauge wheel depth control (BR-NGW) and the single-row air drill with individual gauge wheel depth control (SR-GW). Linear regression lines determined for each drill using data from 5% to 70% emergence.

Table 2. Green pea seedling emergence and early growth results when sown with two hoe-type air drills in 2004.

Drill[a]	Time to First Emergence DAP[b]	SEI[c] (plants m^{-2} dd^{-1})	Emergence Rate (plants m^{-2} dd^{-1})	Final Population (plants m^{-2})	Emergence (%)	Above Ground Dry Matter (kg ha^{-1})
BR-NGW	12.5 b[d]	0.8 a	1.1 b	99.9 a	84.4 a	262 a
SR-GW	15.0 a	0.7 a	1.4 a	97.5 a	82.4 a	273 a

[a] BR-NGW is the banded-row air drill without individual gauge wheel depth control.
   SR-GW is the single-row air drill with individual gauge wheel depth control.
[b] DAP is days after planting.
[c] SEI is speed of emergence index.
[d] Means within a column followed by the same letter are not significantly different by the LSD test (P = 0.10).

since Morrison and Gerik (1985) reported quadratic relationships between final emergence and seeding depth for various crops including alfalfa (*Medicago sativa* L.), wheat, soybeans, and sorghum. In this study, final emergence was not well correlated with seeding depth ranging from 4.5 to 10.5 cm, as a quadratic equation fit to the data had an R^2 of only 0.013. This conflicting result may have occurred because of the high soil moisture content in the seed zone throughout the emergence period and the ability of the large seeded pea to emerge from depths deeper than those considered to be optimum for emergence. Another result that was not expected was that final emergence was not well correlated with the standard deviation of seeding depth. Linear regression equations relating seedling emergence with standard deviation of seeding depth for the BR-NGW and SR-GW drills had R^2 values of only 0.003 and 0.038, respectively. These results are in disagreement with those of Choudhary et al. (1985) who reported that pea seedling emergence in sandy soil was highly correlated with standard deviation of seeding depth ($R^2 = 0.98$). The lack of significant correlation found between emergence and seeding depth uniformity in the present study may be explained by the previously discussed results that emergence was not affected by seeding depth over a range of 4.5 to 10.5 cm and therefore would also not be affected by relatively small variations in seeding depth uniformity.

CROP YIELD

At harvest, plant height of the peas sown with the SR-GW drill was significantly taller by more than 5 cm on average as compared to peas sown with the BR-NGW drill (table 3). This difference may have been due to the fact that the SR-GW placed seeds in a narrow band which caused plants to grow more upright to compete for sunlight as compared to the BR-NGW drill which placed seeds in a wide band. Pea yields are a product of plant population, pods per plant, peas per pod, and pea weight. In this study, there were no differences between the two drills in any of these crop yield components or in crop yield (tables 2 and 3). Plant population, pods per plant, peas per pod, pea weight, and crop yield resulting from use of the BR-NGW drill were all within 6.5% of values obtained with the SR-GW drill and not significantly different. Although Heege (1993) reported higher crop yields with sowing systems that more uniformly distribute seeds over the entire field area, in this study, there was no crop yield benefit for the BR-NGW drill that placed seed in a banded-row as compared to the SR-GW drill that placed seed in a narrow

row. The findings of this study are consistent with those of Desbiolles (2003) who reported that banded-row seeding systems had yields that ranged from equivalent to superior to those of systems that placed seeds in narrower rows and those of Wilkins et al. (1991) who found that although uniform plant spacing can improve pea yield, the effect is dependant on the variety of green pea sown.

CONCLUSION

For the two different types of hoe-type no-till seeding systems evaluated, few performance differences in terms of seeding depth uniformity, emergence, early plant growth, and crop yield were found when seeding green peas in tilled, level soil. The banded-row, flex frame drill without individual gauge wheels for controlling seeding depth (BR-NGW) placed seeds as accurately as the drill that planted seeds in a single-row and was equipped with individual seeding unit depth control (SR-GW). Although the date of first emergence was delayed by 2.5 days for the SR-GW drill as compared to the BR-NGW due a deeper mean seeding depth, there was no significant difference in the speed of emergence as determined by the speed of emergence index (SEI) for the two drills. There also were no significant differences between the two drills in final plant population or the percentage of sown seeds that emerged. For both drills, seedling emergence was poorly correlated with seeding depth ($R^2 \leq 0.013$) and with the standard deviation of seeding depth ($R^2 \leq 0.038$). These results in conjunction with those reported in the literature suggest that in certain field conditions, drills with individual seeding unit depth control have no advantage in seeding depth uniformity or seedling emergence over drills without individual depth control. Further studies on the merits of individual seeding unit depth control are needed in untilled field conditions where soil surfaces would be rougher and have more undulations than the tilled, leveled soil conditions evaluated in this experiment.

Although some researchers have reported higher crop yields with sowing systems that more uniformly distribute seeds over the entire field area, in this study, there was no crop yield benefit for the BR-NGW drill that placed seed in a banded-row as compared to the SR-GW drill that placed seed in a narrow row. Crop yield and crop yield components including plant population, pods per plant, peas per pod and pea weight resulting from use of the BR-NGW drill were all within 6.5% of values obtained with the SR-GW drill and not significantly different. Additional studies are needed in crop years where growing conditions are different and with systems that more uniformly distribute seed over the entire field area to accurately determine if there are yield benefits for banded seed row systems. Information contained in this study can be utilized by equipment designers to improve conservation tillage drill design.

Table 3. Green pea yield components results when sown with two types of hoe-type air drills in 2004.

Drill[a]	Plant Height (cm)[b]	Pods/ Plant	Peas/ Pod	Pea Weight (g)	Tenderometer Reading	Yield (kg ha^{-1})[c]
BR-NGW	52.3 a	5.3 a	6.0 a	0.31 a	99.1 a	6944 a
SR-GW	57.4 b	5.1 a	6.0 a	0.33 a	95.1 b	6582 a

[a] BR-NGW is the banded-row air drill without individual gauge wheel depth control.
   SR-GW is the single-row air drill with individual gauge wheel depth control.
[b] Means within a column followed by the same letter are not significantly different by the LSD test (P = 0.10).
[c] Yield adjusted to a tenderometer reading of 100.

REFERENCES

Allen, R. R. 1988. Performance of three wheat drills in conservation tillage residue. *Applied Engineering in Agriculture* 4(3): 191-196.

AFMRC. 1995. Testing of double shoot opener. Evaluation report 721. Lethbridge, Alberta: Agtech Centre and Humboldt, Saskatchewan: Prairie Agricultural Machinery Institute.

ASAE Standards, 48th ed. 2001a. S526.2. Soil and water terminology. St. Joseph, Mich.: ASAE.

ASAE Standards, 48th ed. 2001b. S477. Terminology and definitions for soil tillage and soil-tool relationships. St. Joseph, Mich.: ASAE.

Chen, Y., S. Tessier, and B. Irvine. 2003. Drill and crop performances as affected by different drill configurations for no-till seeding. *Soil Tillage Res.* 77(2): 147-155.

Choudhary, M. A., G. P. Yu, and C. J. Baker. 1985. Seed placement effects on seedling establishment in direct-drilled fields. *Soil Tillage Res.* 6(1): 79-93.

Desbiolles, J. 2003. Crop yield response to seed bed utilization. System seeding trial results. University of South Australia Agricultural Machinery Research and Design Centre. Adelaide, South Australia: University of South Australia. Available at: www.unisa.edu.au/amrdc/res/proj/seedtrials/. Accessed 9 December 2005.

Doan, V., Y. Chen, and B. Irvine. 2005a. Effect of residue type on the performance on no-till drill openers. *Canadian Biosystems Eng.* 47(2): 29-35.

Doan, V., Y. Chen, and B. Irvine. 2005b. Effect of oat stubble height on the performance of no-till drill openers. *Canadian Biosystems Eng.* 47(2): 37-44.

Heege, H. J. 1993. Seeding methods performance for cereals, rape, and beans. *Transactions of the ASAE* 36(3): 653-661.

Kraft, J. M., and D. E. Wilkins. 1989. The effects of pathogen numbers and tillage on root disease severity, root length, and seed yields in green peas. *Plant Disease* 73(11): 884-887.

Maguire, J. D. 1962. Speed of germination: Aid in selection and evaluation for seedling emergence and vigor. *Crop Sci.* 2(2): 175-176.

Morrison, J. E., Jr., and T. J. Gerik. 1985. Planter depth control: II. Empirical testing and plant responses. *Transactions of the ASAE* 28(6): 1744-1748.

Oviatt, H. S., and D. E. Wilkins. 2002. USDA-ARS Meteorological monitoring in northeastern Oregon. In 2002 Columbia Basin Agricultural Research Center Annual Report, eds. A. Bechtel, H. S. Oviatt and P. M. Frank,16-29. Corvallis, Ore.: Oregon State University Agricultural Experiment Station in cooperation with USDA-ARS, Pendleton, Ore.

Pumphrey, F. V., R. E. Ramig, and R. R. Allmaras. 1975. Yield-tenderness relationships in 'Dark Skinned Perfection' peas. *J. Amer. Soc. Hort. Sci.* 104(5): 507-509.

Pumphrey, F. V., R. E. Ramig, and R. R. Allmaras. 1979. Field response of peas (*Pisum sativum* L.) to precipitation and excess heat. *J. Amer. Soc. Hort. Sci.* 104(4): 548-550.

Raoufat, M. H., and R. A. Mahmoodieh. 2004. Stand establishment responses of maize to seedbed residue, seed drill coulters and primary tillage systems. *Biosystems Eng.* 90(3): 261-269.

Schulman, R. S. 1992. *Statistics in Plain English*. New York: Van Nostrand Reinhold.

Smiley, R. W., M. C. Siemens, T. M. Gohlke, and J. K. Poore. 2005. In 2005 Dryland Agricultural Research Annual Report, eds. D. S. Long, S. E. Petrie and P. M. Frank, 30-50. Corvallis, Ore.: Oregon State University Agricultural Experiment Station in cooperation with USDA-ARS, Pendleton, Ore.

Tessier, S., K. E. Saxton, R. I. Papendick and G. M. Hyde. 1991a. Zero-tillage furrow opener effects on seed environment and wheat emergence. *Soil Tillage Res.* 21(3-4): 347-360.

Tessier, S., G. M. Hyde, R. I. Papendick, and K. E. Saxton. 1991b. No-till drills effects on seed zone properties and wheat emergence. *Transactions of the ASAE* 34(3): 733-739.

Wilkins, D. E., J. M. Kraft, and B. L. Klepper. 1991. Influence of plant spacing on pea yield. *Transactions of the ASAE* 34(5): 1957-1961.

Wilkins, D. E., F. Bolton, and K. Saxton. 1992. Evaluating drills for conservation tillage production of peas. *Applied Engineering in Agriculture* 8(2): 165-170.